Army Battlefield Communications

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The Army Battlefield Communications (ABC) study was carried with support from the Army Research Office during the 1996 JASON Summer Study. The Study Group was asked to access future COTS technologies as to their applicability to Army battlefield communications at the brigade and below levels and to identify research and development efforts needed in implementing the mandate.

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Introduction

The Army Battlefield Communications (ABC) study was carried with support from the Army Research Office during the 1996 JASON Summer Study. The majority of the briefings and documents used by the Study Group in its work were unclassified. This report is unclassified.

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Introduction

(concluded)

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Executive Summary

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Advantages of COTS for the Army

The use of universal data transfer standards will greatly simplify the networking of Army communications systems. As amply demonstrated by the success of the Internet, the use of standard protocols can make radical improvements in the ease of data transfer across widely differing platforms. The use of TCP/IP protocols has been mandated in the Army, including adaptation of legacy systems. We fully agree with this step. The ATM standard should also be adopted by the Army for high capacity links, and the interface between ATM and TCP/IP examined.

The market for sophisticated electronics systems has now largely shifted from the military to the commercial sector. Economies of scale permits COTS technology to offer high performance electronics with wide availability at low cost.

Executive Summary

Advantages of COTS for the Army

(concluded)

Cellular telephone communications systems are designed from the outset as a mobile system. Cellular phones are light weight and low cost, and many necessary features of the system have been worked out, such as hand-off between neighboring cells.

Satellites used as part of a cellular telephone network can provide nearly universal access to remote areas throughout the world.

Digitized voice signals can be easily adapted for data transmission, error correction, and encryption.

CDMA coding provides a form of spread spectrum communication that can be adapted for anti-jam capability and low probability of interception.

Multilevel security systems have been worked out and can be added to a cellular network.

Shortcomings of COTS for Military Use

Commercial cellular telephone and PCS networks use line-of-sight frequencies, ~800 MHz and ~1.8 GHz respectively. Radio signals at these frequencies are strongly absorbed by vegetation and easily blocked by obstructions. Commercial cellular systems use a large network of base stations to mitigate these difficulties, but the need to create a base station network poses problems for military use, as discussed below.

Commercial cellular systems use a fixed network of base stations connected by high capacity, low error rate links. High power and high bandwidth tasks are off-loaded to the base station network to permit the use of light weight handsets. A military system cannot assume the pre-existence of a functional network of base stations in the theater of operations. The base station network must be created using a mix of mobile ground stations, unmanned aeronautical vehicles (UAVs), and satellites. Unlike commercial units, military base stations must be able to maintain high bandwidth connections in a dynamically changing network to accommodate for

Executive Summary

Shortcomings of COTS for Military Use

(concluded)

motion of the mobile basestation units, losses, and poor signal-to-noise ratio (SNR). These requirements are more severe than for commercial systems and will require different approaches to system control and different hardware.

The data transmission bandwidth is generally limited in COTS cellular to values appropriate for voice transmission. The transmission of digital imagery and video will require modifications in coding as well as higher transmit power. The limited bandwidth of commercial cell phones also permits low power jamming of base stations, UAVs, and satellites, even for "spread spectrum" CDMA systems. For example, a stolen CDMA handset could be connected to an rf amplifier of moderate power to saturate all of the channels available in the base station. Current satellites for cellular telephone systems have limited capacity ~1000 channels for large military operations. UAVs and mobile ground basestations will be needed to carry the bulk of the traffic.

R&D to Adapt COTS to Army Needs

These concluding slides summarize a number of areas where research and development efforts are needed to adapt commercial off the shelf communications systems to Army needs.

In recent years it has become clear that the use of commercial off the shelf technology can improve performance and reduce costs for military equipment. Sometimes the extreme point of view has been put forward that the Army need only buy communications equipment built to civilian specifications from commercial suppliers. As described above, military operations place demands on communications systems quite unlike those encountered in the civilian world, and unmodified commercial systems can be used only in limited number of circumstances. A sensible course of action might be to use standards and components from COTS systems where possible, and to conduct research and development efforts to adapt these components to Army needs.

Executive Summary

R&D to Adapt COTS to Army Needs

(continued)

A major area where work is needed is the development of mobile and flexible network of base stations for cellular communications connected by high speed lines. For the amount of traffic needed in large operations, a large number of mobile ground stations and/or UAV base stations will be needed. These base stations can use COTS communications standards with certain changes and additions:

- Adaptive network control will be needed to correct for changing communications links and network topology as a result of motion and losses.

- Priority and timeliness protocols will need to be developed to implement the chain of command in an efficient manner. For example the all to all access in current systems is not well suited to the military, and certain messages - incoming fire - should be handled by the system as rapidly as possible.

- The transmission of pictures and digital data is not yet standard in commercial cellular equipment, and special capabilities will need to be developed for these purposes. A particular concern is the wide bandwidth required by visual images and the associated increases in power consumption.

R&D to Adapt COTS to Army Needs

(continued)

High bandwidth links will be needed to interconnect mobile ground stations. These must be suitable for deployment on a truck or UAV, limiting the antenna configurations possible, and placing special emphasis on low weight and low power consumption. For UAVs these restrictions will be especially severe. Communications links could include high capacity trunk radio, and for ground operations fiber optics links.

Military communications will benefit from the development of high speed data conversion electronics and from advanced power sources.

- Recent progress in microwave digital to analog and analog to digital converters at Rockwell and TRW, sponsored in part by DARPA, point the way to the development of a universal digital radio whose frequency and coding can be programmed by software commands. The commercial world is also very interested in such units, and the price of these new DACs and ADCs could become very reasonable if produced in quantity.

Executive Summary

R&D to Adapt COTS to Army Needs

(continued)

- Improvements in efficiency, and the development of high specific energy fuel cells and other types of advanced power sources are of critical importance to the Army.

The use of commercial satellite systems for military communications should be investigated. A number of new satellite constellations (Globalstar, Iridium, COMSAT, etc.) are in advanced stages of development or early deployment. These are aimed at somewhat different markets and have differing characteristics. For example, the Globalstar system will function as "bent pipe" relays to expand the coverage around fixed ground stations, whereas the Iridium satellites form their own network. Satellites appear well suited to intelligence gathering and special operations, as well as to supplement a ground and UAV based network for improved coverage and reliability. However, the total capacity of planned satellite systems is not sufficient to carry more than a small fraction of the traffic in a major military operation. Global satellite systems with international business agreements may be sensitive to involvement with the U.S. military.

Executive Summary

R&D to Adapt COTS to Army Needs

(continued)

The data bandwidth of COTS cellular radio systems needs to be increased for certain military uses. Cellular telephone systems are typically designed for voice with bandwidths ~10kHz per channel. This bandwidth is insufficient for imagery or serious anti-jam and low-probability of intercept (AJ/LPI) applications. Commercial systems and standards could be modified to increase their bandwidth in a number of ways:

- Combine the 13 channels of current CDMA systems to provide one channel with increased bandwidth (16.5 MHz).

- Investigate optimal coding schemes built on top of the channel architecture of cellular radio systems by switching and combining channels.

- Research AJ/LPI approaches designed on top of commercial coding schemes using wider bandwidth and frequency hopping.

Executive Summary

R&D to Adapt COTS to Army Needs

(concluded)

- Adapt COTS cellular for the transmission of imagery and video. The transmission of imagery in real time will require careful consideration of power and bandwidth constraints, and may lead to protocols as to when such transmissions are made.

Computer software will be needed for military applications. The Battlefield Data Interface and Appliqué are two examples of programs which have been developed to suit military needs.

In using COTS systems, the military should not lose sight of the fact that COTS is not a standard, that COTS systems evolve with the marketplace, and that COTS systems become obsolete. The time scale for changes may often be too rapid for military use, and backward compatibility is not guaranteed. The military will need to analyze its use of COTS systems over the long term and add military standards where needed.

Army Battlefield Communications

Scope of the JASON ABC Study

Future Army communications systems at all levels are mandated to use commercial-off-the-shelf (COTS) technologies to the maximum extent possible. Similar mandates are being applied across all military services.

Use of COTS will fall into three categories: (i) In some cases commercial hardware and software will be readily applicable to Army needs with minimal changes. In addition, commercial networks will carry Army traffic, encrypted for security as required. (ii) In other cases, commercial standards, protocols, and some hardware can be used by the Army, but only after augmentation, say to interface with legacy systems, to enhance anti-jam margins, or add other essential functions. (iii) In special cases where no commercial technology exists that can be adaptable to meet critical Army needs, custom systems will be developed.

The Study Group was asked to access future COTS technologies as to their applicability to Army battlefield communications at the brigade and below levels and to identify research and development efforts needed in implementing the mandate.

Scope of the JASON ABC Study

- Assess and quantify capabilities of future COTS technologies for use in ABC
  - focus on Brigade and Below echelons
- Identify critical R&D issues raised by use of COTS in future ABC systems
  - in some areas COTS will be directly applicable
  - in others COTS will need augmentation
  - in yet others COTS will not be applicable/available

Army Echelon Cheat Sheet

Communications requirements and environments vary as one moves from the highest level of command down the chain to the individual soldier. The echelons brigade and below must be able to perform rapid maneuver in battle, which places greater requirements on flexibility and mobility than is the case at the Corps and Division command levels which are relatively fixed once deployed to theater. At the lower echelons, environmental conditions such as weather, mud, and enemy fire impose requirements for robustness that are not encountered in commercial communication systems.

The new communications architecture is to support vertical communications between echelons and, increasingly, horizontally communications across units in the same echelon.

Army Echelon Cheat Sheet

Corps (XXX)	≥ 2 Divisions plus logistics
Division (XX)	~ 3 Brigades (10,000-18,000) each
Brigade (X)	~ 3 Battalions (3,000-5,000) each
Battalion (‖)	~ 3-5 Companies (~1,000 each)
» Company (|)	~ 2-4 Platoons (100-150) each
Platoon (ooo)	~ 4 Squads (~40)
Squad (oo)	~ 10 soldiers

Rapid Maneuver

Army Vision: Force XXI

The Army Enterprise Strategy (1993) is a unified vision for command, control, communications, computers, and intelligence (C^4I), outlining the principles by which the Army will develop and exploit current and future information technologies. Former Chief of Staff of the US Army General R. Gordon Sullivan, gave this vision the name "Force XXI." Popular expressions of the vision are "information warfare" and the "digital battlefield." The goal of AES is to have widespread deployment of battlefield digital technologies by the year 2010, with initial deployments by 2000.

Traditional Army planning and procurement practices were recognized as too slow and too cumbersome to achieve the stated vision. Past practices would have to be abandoned wholesale—a paradigm shift was a necessity.

Subsequently, the Joint Chiefs of Staff articulated a similar vision (Joint Vision 2010) for the entire US Military. The joint vision calls for US forces to possess information superiority, enhanced jointness, interoperability, be capable of multinational operations, and place increased reliance on information systems.

Army Vision: FORCE XXI

- Army Enterprise Strategy (Force XXI)
  - Split-based, flexible, high tempo, mobile force
  - Information warfare
  - Clear, timely and accurate vision of the battlespace, tailored to each warfighter's mission
- A paradigm change to get there
- Emphasize
  - interoperability over system optimization
  - technology insertion over platform customization
  - rapid application development over prolonged acquisition programs

Early Digital Battlefield Initiatives

The US Army's interest in digital battlefield communication technologies preceded the Army Enterprise Strategy/Force XXI vision by a decade or more. Early program efforts were, however, conceived under the "old" paradigm. The hardware and software under development was custom to the host platform and in many cases permitted little if any interpretability between different Army systems let alone interoperability across military services. The emphasis was on vertical communications. Most seriously, there was a lack of a common technical framework and little attention paid to civilian communications technology. Development cycles for Army communication technologies were many times those of the commercial marketplace and when the custom technologies reached the field, they were obsolete in comparison to the civilian sector. This gap was growing at an increasing rate.

Early Digital Battlefield Initiatives

- Army has supported digital initiatives for the battlefield for well over a decade. Until recently, however:
  - custom hardware (little or no COTS)
  - specialized software
  - little interoperability
  - long development cycles
  - emphasis on vertical vs. horizontal links
  - “stove pipe” systems
  - no common technical framework
- Commercial world far ahead, i.e. Internet

1994 Army Science Board Study

In the summer of 1994 Army Science Board carried out a comprehensive study, "Technical Information, Architecture for Command, Control, Communications, and Intelligence," which had a major and direct impact on the Army. The ASB study was very supportive of the Army's vision and the "reasonable, self consistent and logical decisions" that were being made in the programs supporting Brigade 96, a field exercise designated as the first milestone on the way to realizing the Force XXI vision. However, the ASB was very critical of the fact that there was no one in overall charge of modernization of Army communications, no common technical framework, and the fact that Army programs then underway were not taking advantage of commercial technologies, standards, or protocols.

Recommendations calling for prompt action included: (1) Develop and enforce a Technical Information Architecture that would lead to interpretability of all Army C^3 I systems; (2) Appoint a Technical Architect and give that person full authority to enforce compliance of all Army communication systems; (3) Adopt the Internet standards (IP/TCP protocols) as Army standards: (4) Use open commercial standards as opposed to closed commercial or Army-DOD unique standards; and (5) Redirect a large suite of near-term communication improvements programs then underway and make them compliant with Internet protocol and standards.

Among programs recommended for technical redirection were: Single-Channel Ground and Airborne Radio System Internetwork Controller (SINCGARS INC), Enhanced Position Location Reference System (EPLRS), Intervehicular Information System (IVIS), Tactical Packet Network (TPN), Tactical Multinet Gateway (TMG), and Advanced Field Artillery Tactical Data System (AFATDS). These and other near-term communication programs represented an Army investment of approximately $ 5.6 billion over five years.

1994 Army Science Board Study

- Recommendations
  - Create "Technical Information Architecture" — interoperability of all ARMY C^3I systems (1 yr)
  - Put one person/office in charge
  - Use Internet technology/standards as foundation
  - Augment with other open commercial standards
  - Redo suite of improvement programs then underway (~$5.6 B/5 yr)
    - SINCGARS-INC (Internetwork controller)
    - EPLARS (Enhanced Position Location Reporting Sys.)
    - IVIS (Intervechicular Information System)
    - Other (TPN, TMG, AFATDS, ...)

1994 Army Science Board Study

(concluded)

Other major recommendations of the 1994 ASB study were: (6) Don't procure equipment for Brigade 96 designed according to the DOD standards prescribed in MIL-STD-188-220 (later revised to MIL-STD-188-220A); (7) Make full vertical and horizontal connectivity the goal; (8) Reconsider excessive communication security requirements, especially at the SCI level; (9) Re-analyze the jamming threat, recognizing that setting anti-jam requirements is a trade-off between proliferation of relatively low-cost communication networks to ensure connectivity vs. custom systems built against the worst-case scenario, which inevitably precludes leveraging of commercial technology. (10) Army and Army contractor personnel should participate in communication technology standards boards and meetings to insure that the Army's needs and perspective are considered; (10) The Iridium, Globstar, and Teledesic LEO satellite-based communications systems were cited as examples of commercial technologies that will be available to enemies and/or terrorists, but not the Army if it didn't reconsider its policies.

1994 Army Science Board Study
(concluded)

- Don't build Brigade 96 to MIL-STD 188-220 standards (Later revised in MIL-STD 188-220A)
- Goal: full vertical and horizontal connectivity
- Review real COMSEC needs: "Excessive caution about security needs is Maginot Line of information warfare."
- Re-consider jamming policy and avoid building everything against the "worst case threat"
- Participate in relevant standards boards and fora
- Iridium, Globalstar, Teledesic,... cited as prime examples of systems that Army could leverage

ABC Accomplishments

The recommendations of the 1994 ASB Study have already brought about major changes in the Army's plans for achieving the AES/Force XXI vision.

A Technical Architect was promptly appointed and by January 1996, Version 4.0 of the Army Technical Information Architecture (ATA) was released. The ATA is a "building code" to insure interoperability and standardization, not a blueprint for building an actual system. Included in the ATA is full adoption of the TCP/IP protocols with adoption of the Asynchronous Transfer Mode (ATM) switch protocols delayed until the commercial sector sorts out issues associated with interfacing these two different ways of transferring digital information.

The Army Battlefield Communications system is seen differently by different communities. In addition to the Technical Architecture, one can identify the Operational Architecture that relates to the way Army officer view the system, and the Systems Architecture that speaks to system engineers.

ABC Accomplishments

- Army "Technical" Architecture (ATA) exists
  - Version 4.0, Jan. 1996
  - A building code not a blueprint
  - TCP/IP protocols adopted (add ATM in future)
  - ATA served as basis for a Joint Technical Architecture
- Also need an "Operational" Architecture
  - The way Army officers view things
- And a "Systems" Architecture
  - The way systems engineers view a communications system

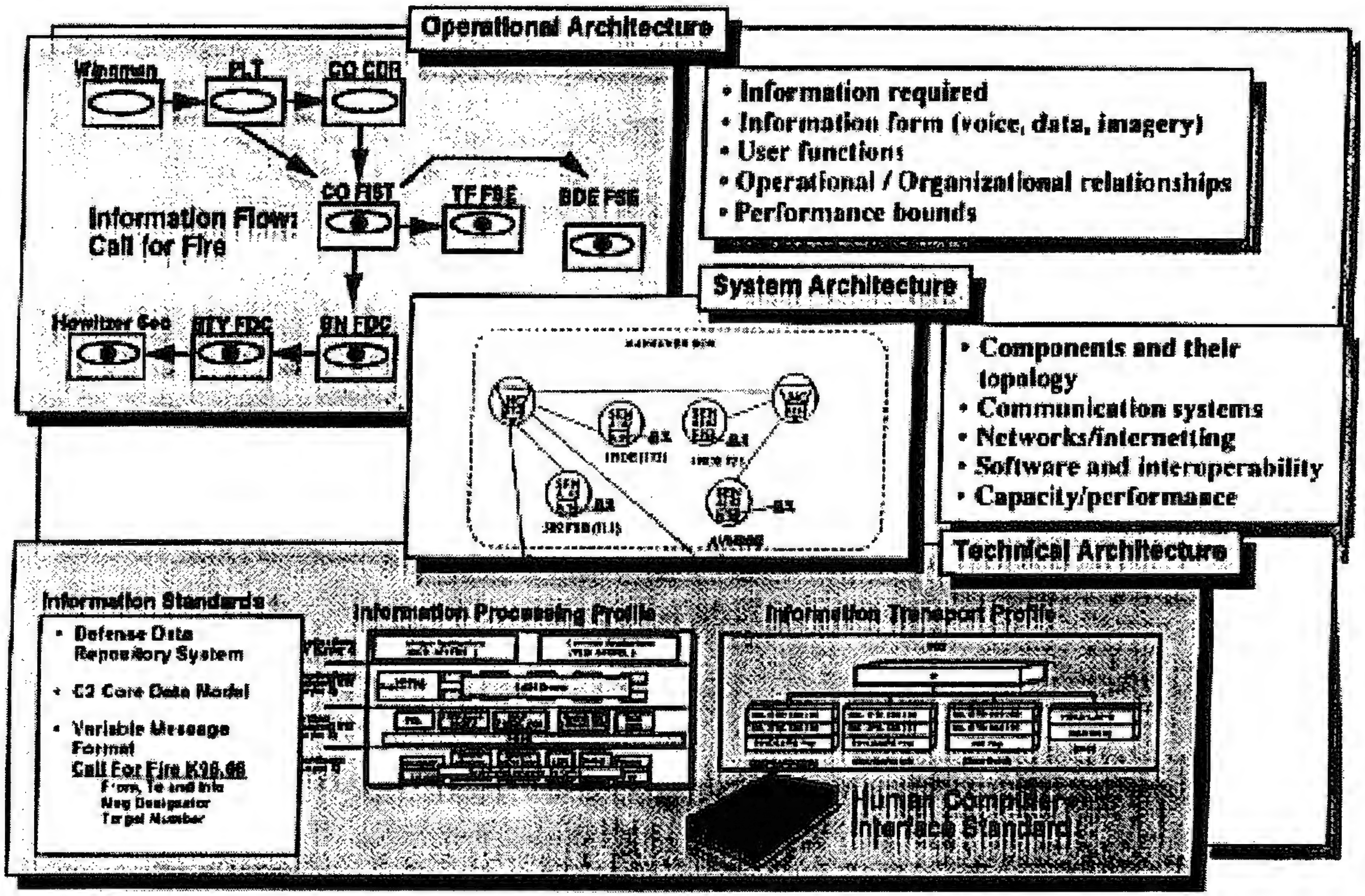
The Three Architectures

The Operational Architecture specifies the missions, user functions, tasks, information requirements, information types (voice, data, imagery) and operational and organizational relationships of all parties exchanging information.

The System Architecture is the physical implementation of the Operational Architecture, the components and their topology, the networks and internetting, the communication systems, software and interoperability, and the capacity and performance standards.

The Technical Architecture specifies the standards and protocols for information storage, information processing, and information transfer. An especially critical part of this architecture is the Hunan Computer Interface Standard.

The Three Architectures



Advanced Warfighter Exercises

In addition to those recommendations of the 1995 ASB Study already completed, the Army has accomplished a great deal more as well. Several small Advanced Warfighter Exercises (AWE) have been held in which prototype or surrogate hardware and software is tried out in field exercises to evaluate utility, suitability, performance, and user reactions. A Brigade-level AWE is planned for Ft. Irwin in the spring of 1997 in which surrogate digital communication equipment will mimic devices still under development. A Division-level Advanced Warfighter Exercise is planned for a future date. A wealth of practical data and experience is becoming available.

Advanced Warfighter Exercises

- Many other recommendations of ASB 94 have been implemented (leadership, control of budgets, tech. support, participation in standards fora)
- Several small sized Advanced Warfighter Exercises (AWE) have already taken place
- Brigade-level AWE is scheduled at Ft. Irwin in March 1997
  - surrogate equipment (Appliqué, Surrogate Digital Radio, ...) to used in places
  - execrise will employ ~1,200 computers
- Division-level AWE planned as next big step

ABC Requirements

As stated earlier, the Army Technical Architecture does not specify what the Army Battlefield Communications system must do, i.e., who must communicate with who, what information needs to be passed, what are the priorities, etc. Communication requirements for the actual system are generated by the Army Training and Doctrine Command (TRADOC). In setting such requirements, TRADOC coordinates with the technical community at the Army Signal Center and other commands of the Army.

In accord with current TRADOC requirements, the Army Signal Center is developing the Warfighter Information Network (WIN), an Operational Architecture. This will be expressed as an System Architecture (an actual system) over time as COTS based technologies are introduced, supplemented where necessary with custom technologies. The Technical Architecture comes heavily into play in the latter stages, but it also plays a major role in the initial stages by helping to avoid specifying requirements that would be overly expensive, technically unsound, or preclude COTS.

ABC Requirements

- The Technical Architecture does not specify actual operational requirements
- TRADOC sets these requirements in coordination with with Army Signal Center (Ft. Gordon)
- The Warfighter Information Network (WIN) under development at Ft. Gordon is the corresponding operational architecture
- WIN will be expressed over time as a physical system (systems architecture) in accord with the technical standards and protocols of the Army Technical Infromation Architecture.

General Technical Issues

The following outlines technical issues of general importance to the Army. These are discussed more fully in the following view graphs.

Uniform standards are essential for the transfer of digital information in the military. The use of TCP/IP protocols has been mandated, and will be a major improvement over past practice. However important compatibility issues remain.

A major uncertainty at present, both in the commercial sector and in the military, is the integration of ATM standards developed for digital telephony with TCP/IP standards developed for digital file transfer.

The frequency of operation of wireless links and their bandwidth impose important constraints on military use. Microwave signals are more sensitive to blockage by foliage and terrain. Commercial communications equipment typically has limited bandwidth.

The military requires multilevel secure communications over digital networks. Multilevel security protocols have been worked out by NSA and seem ready for application in digital networks.

A battlefield data interface is needed to filter the wealth of information which will be available over a military network. Speed and ease of use are important as well as the decisions on who has access to what information.

General Technical Issues

- Uniform standards for bit transfers in military
  - TCP/IP protocols mandated
- Integration of ATM and TCP/IP
  - telephone vs. email
- Frequency and bandwidth tradeoffs
  - GHz signals blocked by foliage and terrain
  - limited bandwidth of commercial implementations
- Secure communications over unsecure links
  - Multilevel security
- Information Filtering
  - Battlefield data interface - speed and ease of use important

TCP/IP Protocols

The TCP/IP protocols, well known from their application in the Internet, are a layered protocol suite. The top layer is the application, for example an email or file transfer program, the next is the transport layer which arranges the digital information into packets for transmission, the next is the network layer which routes the transmission of the data packets through the network, and the lowest is the link layer which interfaces data transmission to the physical link used to transmit the data, for example a fiber optic link. The key feature which makes the TCP/IP protocols so useful is the fact that programs operating at higher layers do not need to know any of the specific details of implementation of the lower layers. For example a person sending email need not know the route it travels, or the type of computer the recipient is using. This advantage is very powerful and has led to the exponential growth of the Internet.

TCP/IP Protocols

Layered Protocol Suite

Application	e-mail, FTP, etc.
Transport	TCP - packets
Network	IP - routing
Link	interface to physical link

ATM vs. TCP/IP

ATM is a digital data transfer protocol developed for digital telephony, which has somewhat different characteristics than the TCP/IP protocol. With ATM a virtual circuit (or route) is established through the digital network at the beginning of the call. The virtual circuit is assigned certain attributes, such as the desired bandwidth. The use of a single path guarantees the continuity and ordering of the data, and very high speeds can be achieved. These properties are desirable for the transmission of real time data - digitized voice and video for example. However, the integrity of the data is not automatically checked, and ATM virtual circuits are subject to losses and disruption.

TCP/IP by contrast was developed for reliable data transfer. The route of each packet through the network is individually decided, and different packets can travel by different routes. This scheme makes efficient use of the network and avoids blockages, but the timing and ordering of received packets is not guaranteed. The bandwidth of data transfer is also not controlled. Users of the world wide web are familiar with the resulting irregular delays in the receipt of data, making TCP/IP networks somewhat less suitable for the transmission of real time data. On the other hand, data integrity is checked for each packet and faulty packets are retransmitted, so that the network can adaptively respond to losses and disruption, and the final message received is error free.

Both standards are in wide use, and a battle between them is currently ongoing in the commercial sector. The outcome is not yet clear, but could have important consequences for military networks. The two standards are not entirely incompatible, and future commercial networks will likely mix both. For example TCP/IP data can be transmitted over an ATM network. In the future the interface between TCP/IP may move all the way into the user's computer, so that the network itself could be ATM. This solution would be favored, for example, to provide digital movies to a user who occasionally sends email. The resolution of these issues will have important implications for the compatibility of military networks with commercial equipment.

ATM vs. TCP/IP

- ATM
  - developed for digital telephony
  - virtual circuit established at beginning of call
    - continuity and monotonicity
    - can achieve very high speed
  - data integrity not checked
- TCP/IP
  - developed for data networks, internet
  - many transmission paths possible for single message
    - timing and ordering of packets not quaranteed
  - data integrity checked
- Future boundary between TCP/IP and ATM uncertain

Data Rates for Desert Storm

This slide summarizes data rates required for Desert Storm; the information is taken from the JASON Global Grid study. As shown, the data rate is dominated by the imagery and intelligence.

Data Rates for Desert Storm*

Qty	Type	Size	ave rate (bps)	peak rate (bps)
200,000	voice calls/day	400 sec	1E6	7E6
10,000	documents/day	100 MB	1E7	1E7
80,000	mi^2 imagery/day	3E7 b/mi^2	3E8	8E8
200	video conf. ch.	1E5	5E6	2E7
1	intel data stream		3E8	3E8
	total		6E8	1E9

*from JASON Global Grid Study

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Bandwidth Considerations

Bandwidth is a critical limitation for military communications. In order to assess the magnitude of the problem, we summarize data rates for Desert Storm.

Desert Storm required a total data rate ~1 Gbps, dominated by imagery and intelligence information. The total rate greatly exceeds the capacity of commercial communications satellites. The average data rate per soldier ~2kbps was adequate for voice communications but not imagery.

Bandwidth is a fundamental constraint for battlefield communications. Visions of future command and control systems can require tremendous data rates. For example, providing video links (>1Mbps) between a million solders would require a bandwidth (>1Tbps) so large that it is simply not available in the accessible electromagnetic spectrum. Power source requirements are tied to bandwidth. Because the received energy per bit must exceed kT, the transmit power is proportional to bandwidth, as discussed below, so high bandwidth requires high power. The weight of batteries is already a severe problem for Army operations, as described below, and increased average bandwidth increases this weight proportionately. Exploring means to allocate the available bandwidth in the most efficient manner to permit high bandwidth communications where and when needed should be a research priority.

The total bandwidth of a commercial off the shelf (COTS) cellular telephone base station using all channels is typically ~ 10 Mbps. A single user requiring this bandwidth (e.g. for

Bandwidth Considerations
(concluded)

video transmission) would saturate the system locally. In order to provide cellular service for military operations, a large number of mobile base stations are required. If unmanned aeronautical vehicles (UAVs) are used as base stations, 100 UAVs at 10 Mbps each would be required to provide the bandwidth (1 Gbps) for Desert Storm, and 100,000 UAVs would be needed to provide 1 Tbps.

The limited bandwidth of commercial cellular telephones (~10 MHz) permits only limited spectral spreading, which will likely be inadequate for anti-jam and low probability of interception techniques.

Bandwidth Considerations

- Desert Storm
  - total data rate (1Gbps) greater than capacity of one satellite
  - rate per soldier (2kbps) adequate for voice but not imagery
- Visions of the digital battlefield of the future often require very large data rates
  - video (>1Mbps) for a million solders is > 1 Tbps
- COTS cellular BW typically limited to ~10 Mbps
  - large number of mobile base stations required (100 UAV's for 1 Gbps, 100,000 UAV's for 1Tbps)
- COTS cellular BW inadequate for anti-jam, anti-fade
- Bandwidth considerations are critical

Data Rate Comparisons

This slide summarizes the capability of various military and commercial systems. The current SINCGARS radio has bandwidth (4.8 kbps to 9.6 kbps) appropriate for voice communications, but limited for data. The largest bandwidth radio system, high capacity trunk radio (HCTR) has bandwidth 45 Mbps. Far greater bandwidth is achieved with optical fiber systems, up to 2.1 Gbps for OC-12, with continued improvements expected in the future. Optical fiber has additional advantages that it is low power and that the available electromagnetic spectrum can be shared by different channels in different fibers. Fiber is well suited for high bandwidth connections between ground base stations, but has obvious limitations for mobile applications.

Data Rate Comparisons

✳ SINCGARS	4.8 kbps
✳ SINCGARS-SIP	9.6 kbps
✳ MSE	16 kbps
✳ EPLRS (not networked)	19.2 kbps
✳ EPLRS/V (“ “)	57 kbps
✳ NTDR (“ “)	288 kbps
✳ FDR	20 Mbps
✳ HCTR	45 Mbps
→ Telephone	64 kbps
→ T-1	1.544 Mbps
→ T-3	45 Mbps
→ OC-12 (Fiber/ATM)	2.1 Gbps

Multilevel Communications Security

A single interconnected network, such as the Internet, is conceptually attractive for military applications, because it permits universal access by all users. Current military networks are not of this type, for partly historical and partly security reasons. The maintenance of different levels of security for different users in a single network is a potentially serious problem.

Multilevel security has been carefully examined in the Multilevel Information Security Initiative with the NSA having lead responsibility. Technical solutions to the security problem have been worked out, and we do not see major research issues for the Army in the narrow area of multi-level security.

However the implementation of an interconnected military network will be a major undertaking, posing serious problems in other areas.

Multilevel Communications Security

- NSA has lead responsibility
- Multilevel Information Security Initiative (MISSI)
- Government wide solution for Secret High.
  - Fortessa & Fortessa+ public key encryption card inserts into any handset/radio/computer
  - Each user has card and PIN, which together provide
    - Authentication
    - Availability and access control
    - Data integrity and confidentiality
    - Non-repudiation
  - Vulnerability: card & PIN captured
- Extendable to TS and SCI levels (NSA job)
- We see no major technical issues for Army here

User-Battlefield Data Interface

Initiatives like the Force XXI/Warfighter Information Network will provide military users with access to vast amounts of data. Computer interfaces such as Appliqué and the Battlefield Data Interface have been developed with many of the features described below.

The human/computer interface between military users and the battle information database requires care to insure that important information is not overlooked (e.g. enemy aircraft which pose a threat), provide ease of use for a broad range of users, and avoid saturating the network with unnecessary data flow.

Classical decision support software generates menus of options for users to consider. The user evaluates the list and makes a decision, assuming that they have adequate time. These appear to be ill suited to battlefield conditions where commands are issued and quick decisions are often required.

User-Battlefield Data Interface

- Force XXI/Warfighter Information Network will provide users access to vast amounts of data.
- Support software needed to
  - insure that important information is not overlooked
  - prevent user overload
  - avoid saturating network with unnecessary data flow
- Classical decision support software generates list of options for user to consider
  - user evaluates list and makes a decision
  - assumed that user has ample decision time
  - ill-suited to conditions of the battlefield

User-Battlefield Data Interface

(continued)

The military decision making process is based on the recognition and evolution of patterns of troop and equipment deployment. It appears no commercial system is directly applicable, and that the development of such software must be a dedicated effort.

An annotated graphical interface is a natural way to present battlefield information in an immediately useful form. Alerts via flashing or color change could be used to highlight important new information. Intelligent systems design can be used to reduce the demands on short term memory of the user in a number of ways. Maps with unit locations classified as friend, foe, or unknown, could be used with a click feature to show the history of prior positions. Weapons could be highlighted along with their range. A summary of prior actions could be shown, along with the rules of engagement.

User-Battlefield Data Interface

(continued)

- Military decision-making process
  - based on recognition of patterns and temporal development
  - software requires a dedicated developmental effort (not COTS)
- Annotated graphical interface
  - quickly grasp information
  - provide alerts to important new information
  - reduce demand on short term memory
    - show maps with unit locations classified friend, foe, or unknown, click to view history of prior positions
    - show weapons and ranges
    - show summary of prior actions, compare with rules of engagement

User-Battlefield Data Interface
(concluded)

The WIN (Warrior Information Network) will require continued development and upgrades as the use of networks expands.

Bandwidth is a critical resource in military networks, and well designed interface software must minimize bandwidth requirements by using intelligent agents to anticipate the data most likely to be needed, and to provide additional data only upon user request.

Network management software cannot anticipate all events, and the user must be able to retain control over what information is provided.

User-Battlefield Data Interface

(concluded)

- Development and continuing up-grades of battlefield software will be required for WIN
- Well designed support software will minimize stress on limited bandwidth of battlefield networks
  - anticipate data most likely to be needed
  - provide additional data only upon user request
- Support software *cannot* encompass all contingencies
  - User must retain positive control
  - User able to over-ride system

Advantages of COTS Cellular Technology

Commercial off-the-shelf cellular telephone technology has many advantages: mobile operation is basic to the system, and cellular telephones are small, and light weight; the line of sight limitation allows a number of users to operate on the same frequency in different places, and is compensated for by the use of many base stations, UHF operation can provide relatively wide bandwidths; and the wide application of COTS units leads to low cost.

Digital voice operation has many advantages: digital hardware is cheaper than analog, error protection and correction are possible with digital voice; digital data can be added to digital voice systems easily; and digital voice transmissions can be easily scrambled with flexible encryption.

Advantages of COTS Cellular Technolgy

- Advantages of COTS cellular systems
  - mobile operation basic to system
  - line of sight limitation compensated by many base stations
  - UHF operation can provide relatively wide bandwidths
  - wide use of COTS technology leads to low cost
- Advantages of Digital Voice Operation
  - digital hardware generally cheaper than analog
  - error protection and correction possible with digital voice
  - digital data can be added easily
  - voice transmissions easily scrambled with flexible encryption

Advantages of COTS Cellular
(concluded)

CDMA cellular systems have a number of advantages for military applications:

CDMA systems use spread spectrum coding which could be adapted to provide effective anti-jam and low probability of intercept capability if additional bandwidth is made available.

CDMA systems can be easily adapted to provide secure voice encryption

Advantages of COTS Cellular

(concluded)

- Advantages of Code Division Multiple Access (CDMA)
  - Easy adaptation to anti-jam and low probablity of intercept if additional bandwidth is made available.
  - Easy adaptation to secure voice encryption - privacy standard.

TDMA vs. CDMA

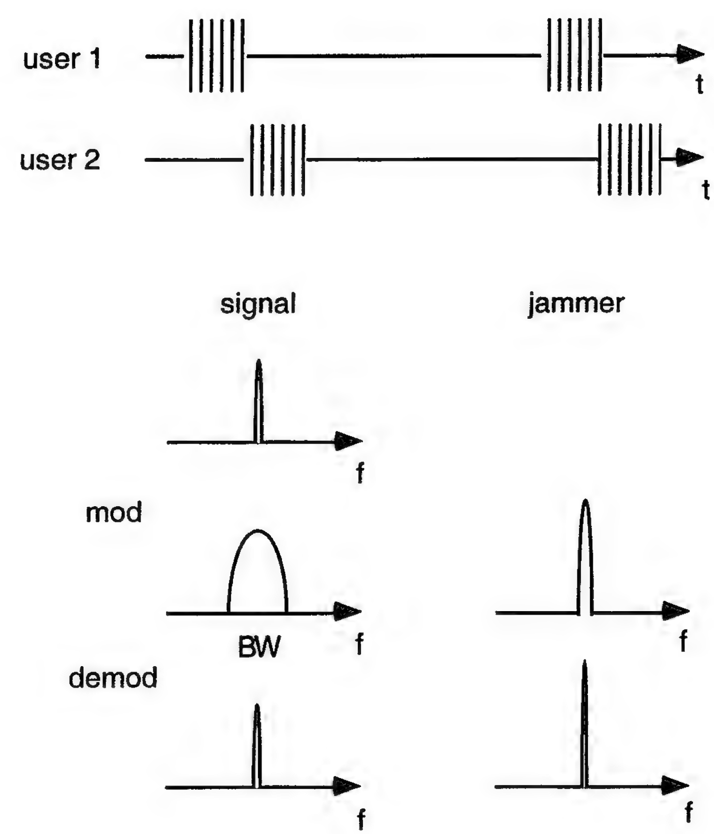
This slide compares two approaches which permit multiple users on the same frequency channel: time division multiple access (TDMA) and code division multiple access (CDMA). Older cellular telephones accommodate multiple users by simply using a large number of channels.

TDMA users share the same communications channel by subdividing the available time to users in sequence, as indicated schematically. The resulting modulation spreads the voice signal of a single user over a wider bandwidth as a consequence of time compression, as indicated. TDMA systems are relatively simple, and are tolerant to large differences in signal strength between different users in a cell. However, TDMA systems do not reject narrow band jammers, because the jammer is demodulated with each signal and continues to interfere.

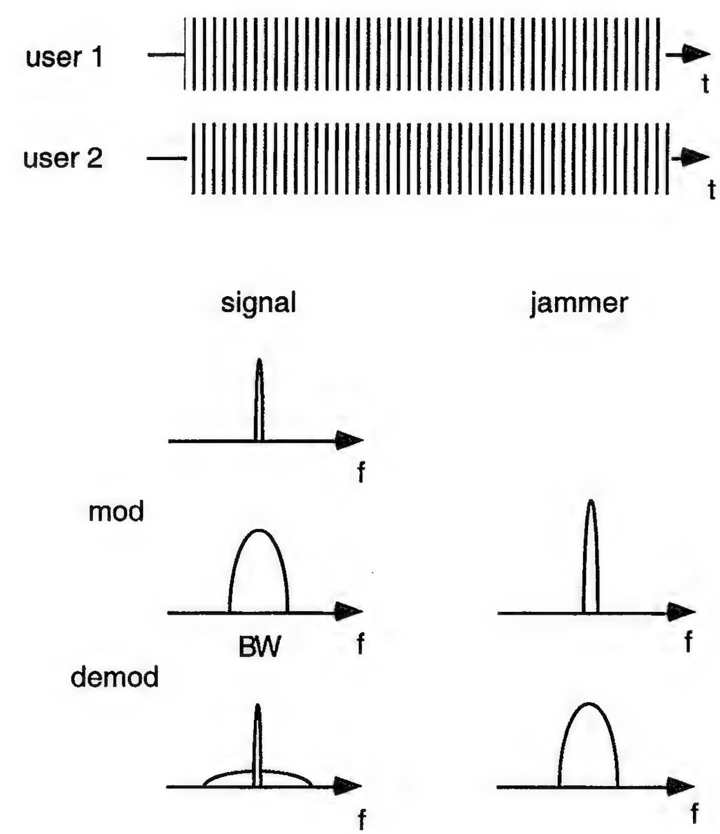
CDMA users share the same communications channel simultaneously by multiplying the voice signal from each user with a different pseudorandom code clocked at a higher frequency, which determines the bandwidth of the channel. The resulting signal is spread spectrally as indicated by the ratio of the code frequency to the signal bandwidth. On demodulation the narrow band voice signal for the desired user is recovered by multiplying once again with the same code, while the signal for other users remains spread as indicated. Thus the signal from other users appears as broadband noise and can be rejected by a narrow band filter. The degree of rejection is equal to the ratio of the spread to unspread bandwidth. CDMA systems theoretically permit many more users per channel than TDMA systems. Another advantage of CDMA is that narrow band jammers are rejected by spreading in the demodulation process as indicated. However CDMA systems only work well if the signal strength from multiple users is comparable, and require gain balancing via feedback signals from the base station to the individual cellular telephones. This consideration reduces the actual number of users for a CDMA system to values below the theoretical limit.

TDMA vs. CDMA

TDMA



CDMA



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Network Topologies

Network topology is a critical issue for battlefield communications. The slide compares the SINCGARS radio network topology currently used for battlefield radios, to commercial cellular telephone systems, and the planned Globalstar satellite telephone system.

Unlike commercial systems, military radio networks cannot rely on the existence of a network infrastructure.

A SINCGARS network consists of a number of digital radios which both transmit and receive signals directly as well as relay signals from for other SINCGARS radios. The resulting network topology is defined by the present location of the participating radios and changes dynamically as the radios change position, and as the strength of the radio links changes. The dynamic nature of the network is well suited to operation in foreign territory, in that no infrastructure is necessary and the system can be operated for a small number of users, but poses problems for network management and scaling to large numbers of users, which have been addressed in Army research.

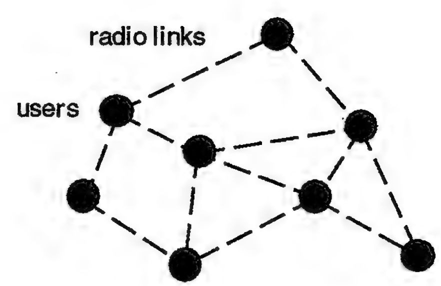
Commercial cellular telephone networks require the existence a large infrastructure before anyone can use the system. As shown, the network consists of a number of fixed base stations, one per cell, connected via high capacity land line or trunk radio links. Individual cellular telephones are connected via low power radio links to a nearby base station. This arrangement permits the use of small light weight cellular phones, because the network functions are performed by the base stations. The base stations themselves are neither small nor light weight.

Network Topologies
(concluded)

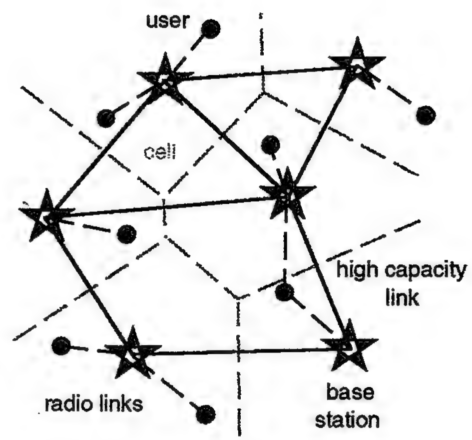
The planned Globalstar system is an example of a satellite-based cellular telephone system. As illustrated, a constellation of satellites is used to relay the signal from a small handset directly to a ground station, which is connected to the telephone network via high capacity land lines or trunk radio links. The use of a satellite relay in the Globalstar system permits a single ground station to cover much larger area than conventional cellular systems. Because the area of coverage for Globalstar satellites is centered around fixed ground stations, they are well suited to providing coverage to a certain area, e.g. a metropolitan area, or theater of operations. The size of the area is comparable to the height of the orbit, about several hundred miles. Other satellite systems permit remote coverage internationally by using satellite relays (Iridium) or geosynchronous orbits (COMSAT). Remote coverage, both within the theater of operations and internationally, are strong advantages for military operations.

Network Topologies

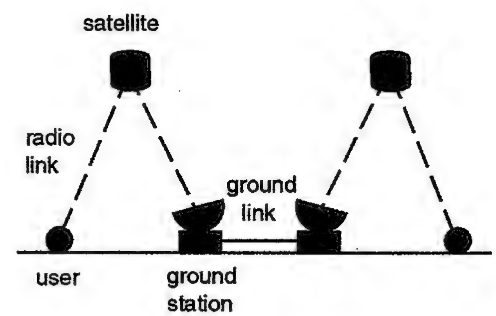
SINCGARS



Cellular



Globalstar



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Shortcomings of COTS Cellular for Army

Cellular telephone systems have well known advantages, they are small and light, and the broad application of cellular technology has made sophisticated telephone technology available at low prices. However, commercial off-the-shelf cellular systems have serious shortcomings which must be overcome for military use.

Commercial cellular systems rely on static networks of fixed base stations. One cannot safely assume that such a network would exist in the area of operations, or that it would be available for military use even if it were present. Furthermore, the full network is required to provide service even for a small number of users. In order to build a military cellular system, a network of mobile base stations is needed, located on trucks, UAVs, or other platforms. These mobile base stations must be connected to each other and/or to fixed ground stations via high capacity links. Military networks are dynamic rather than static, because base stations move, and because the stations and their data links can be destroyed. Thus the systems control of military cellular networks is different and more difficult than for commercial networks.

High capacity links are required to connect mobile base stations to each other and/or to connect mobile base stations to fixed stations which act as interfaces to the full military communications network. High capacity trunk radio (HCTR) operating at 45 to 155 Mbps is a natural choice for links to mobile platforms. Disposable optical fiber links could be used for semi-permanent links. Communication via satellite relays, commercial or military, could also be used.

Shortcomings of COTS Cellular for Army
(concluded)

Anti-jam (AJ) and low probability of intercept (LPI) techniques are not fundamental to COTS cellular and need to be added on. Although CDMA systems are spread spectrum, the degree of spreading is not large enough to provide effective protection against jamming and intercept.

Commercial off-the-shelf cellular systems employ narrow bandwidth channels suited to voice communications. The Army needs wideband channels to provide AJ and LPI capability and to permit high data rate transmissions of video signals, imagery, and data.

The Army also needs better security than provided in COTS systems. Encryption of digital voice data will need to be added.

Shortcomings of COTS Cellular for Army

- COTS relies on static network of fixed base stations.
  - base station infrastructure not available in enemy territory
  - infrastructure required even for small number of users
- High capacity lines needed between base stations.
  - high capacity trunk radio (HCTR) (45 to 155 Mbps)
- Anti-jam (AJ) and low probablity of intercept (LPI) not fundamental to COTS cellular.
- COTS uses narrowband channels whereas Army needs wideband.
  - provide for AJ and LPI
  - allow high data rate transmission for video and imagery
- Army needs more secure voice than COTS

Adaptation of COTS Cellular for Army

COTS cellular systems can be adapted in a number of ways to provide for Army needs.

Cellular base stations need to be adapted to mobile operation in trucks, UAVs, and other platforms. Dynamic network management needs to be introduced which permits changing network topology and compensates for motion of the base stations, changes in signal to noise ratio, and losses.

High capacity links between base stations can use many COTS components, for example terrestrial line of sight or airborne HCTR relay, ATM switches and optical fiber.

CDMA channels could be combined in order to obtain higher bandwidth for AJ/LPI and for video transmissions and imagery.

Functions could be added for the Army. One to many broadcast could be used to transmit material such as maps with troop and equipment positions. The control of cellular systems should be modified to incorporate timeliness and priority protocols, to permit urgent messages such as "incoming fire" to override other traffic, and to control access up and down the chain of command.

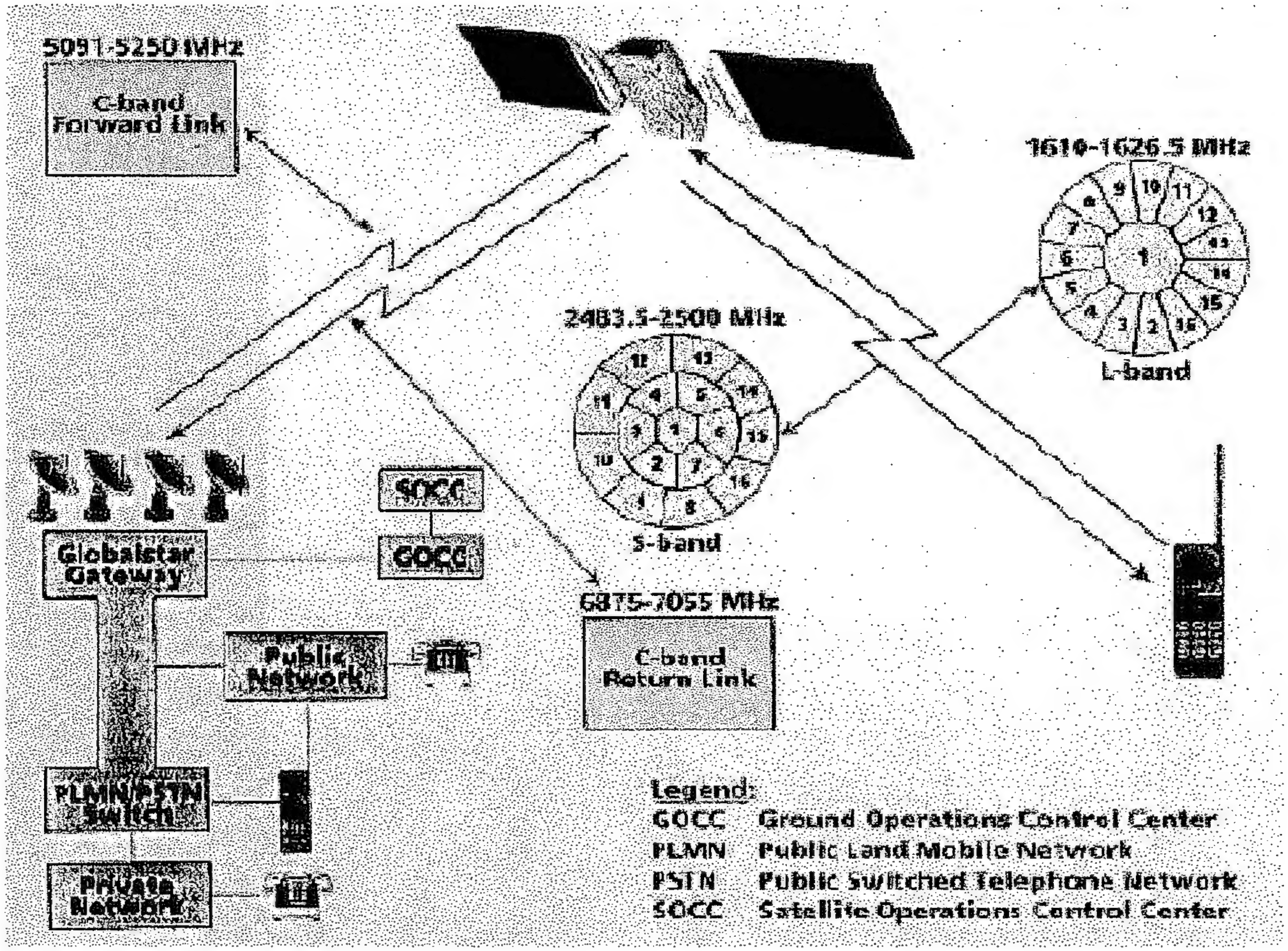
Adaptation of COTS Cellular for Army

- Adapt base stations to mobile operation
  - mobile ground stations, UAVs
  - dynamic network management - motion, losses, SNR
- High capacity links could use COTS elements
  - terrestrial line of sight or airborne relay for HCTR
  - ATM switches, optical fiber
- Combine CDMA channels for higher bandwidth
  - imagery, video transmissions
  - antijam, low probability of intercept
- Add functions for Army
  - one to many broadcast
  - timeliness and priority protocols

Globalstar

This slide from QUALCOMM illustrates some features of the Globalstar satellite communications system. As illustrated, cellular phones communicate with the satellite via an L-band uplink and an S-band downlink. The antenna patterns for the uplink and downlink are divided into 16 cells, as indicated, each with 16.5 MHz bandwidth, in order to increase the number of users. The satellite communicates with a ground station - a Globalstar Gateway - via two C-band microwave links of ~170 MHz bandwidth which combine the signals from the 16 cells. Each Gateway is directly connected to the public telephone network via high speed lines.

Globalstar



5091-5250 MHz
C-band Forward Link
1610-1626.5 MHz
L-band
2483.5-2500 MHz
S-band
6875-7055 MHz
C-band Return Link
SOCC
GOCC
Globalstar Gateway
Public Network
PLMN/PSTN Switch
Private Network
Legend:
GOCC Ground Operations Control Center
PLMN Public Land Mobile Network
PSTN Public Switched Telephone Network
SOCC Satellite Operations Control Center

Military Use of Globalstar

The Globalstar system could be useful to the Army if appropriate modifications are made.

The wide bandwidth needed for anti-jam and low probability of intercept could be achieved by using the full bandwidth of 16.5 MHz available in each cell of the satellite antenna pattern, by combining the 13 channels available, each 1.25 MHz wide.

Globalstar gateways are physically large and heavy, but probably could be transported in C5 aircraft, or on ships.

The Globalstar satellites could be used as the basis for a modified Army satellite communication system. To reduce cost the satellites could be purchased as currently configured; each satellite simply operates as a relay without local processing (bent pipe). The changes required for an Army system could be made in custom gateway ground stations, programming of the system, and user equipment. The cost of 48 satellites launched into orbit is estimated at $1 billion, or about $20 million each, an economical figure in comparison with most current satellite programs. However, this estimate is based on the use of Russian and Chinese launch vehicles, which seems inappropriate for a US. military system.

Nominally identical satellites financed by the commercial sector and by the military could be mixed in a single system, which would hide Army use. Because the Globalstar satellites simply relay signals locally between cell phones and the Gateway, the same satellite in the same orbit could provide commercial service over the U.S. and military service overseas. During conflicts commercial satellites could be shifted to military use if necessary to provide additional capacity. While technically feasible, arrangements of this type may open legal questions. Global communications business may also be reluctant to work with the U.S. military, because they must make formal agreements with foreign nations to provide service.

Military Use of Globalstar

- Need wide bandwidth for anti-jam, low prob. intercept
- Work within commerical Globalstar system
  - Multiplex over 13 (1.25 MHz) channels = 16.5 MHz BW
  - Transport gateway in C5 aircraft or ship
- Use Globalstar as basis for Army satellite system
  - Purchase satellites as currently configured - “bent pipes”
  - Cost of 48 satellites is $1B (launched by Russia and China)
  - Custom gateway ground stations and user equipment
- Add adjunct of military satellites to Globalstar system
  - In peacetime the mix hides Army users.
  - In war adjunct sats supplemented by part of commercial system.

Multimode Digital Radio

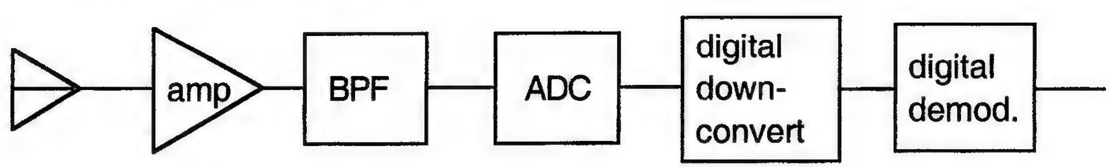
Both commercial and military users would like a universal cellular radio set capable of operating on multiple frequency bands with user programmable modulation and coding. For the Army, such a radio would permit backward compatibility with legacy systems, and emulation of foreign friend and foe radio systems, while permitting the use of new modulation and systems approaches. A number of programs have addressed this goal, including the DARPA "Speakeasy" program and the "software" radio request for information from Bell South. However, current "Speakeasy" implementations simply strap together a collection of different radio sets, and the BellSouth program is not yet produced concrete proposals.

Recent advances in ultra-high speed analog to digital converters may enable the design of a truly universal cellular radio set. With DARPA support, both Rockwell and TRW have made prototype analog-to-digital and digital-to-analog converter chips based on heterojunction bipolar transistor technology (HBT). Rockwell has demonstrated an 8 bit 3 gigasample per second analog-to-digital converter and a 12 bit 1 GHz digital-to-analog converter; TRW has demonstrated a 4 bit 3 gigasample per second analog-to-digital converter. These companies claim that the cost of these chips could be low enough if bought in large quantities to allow their use in commercial cellular telephones.

The block diagram of a universal multimode digital radio based on a GHz ADC illustrates the simple structure. The UHF or microwave signal is digitized immediately following a preamp and bandpass filter, and the signal is digitally downconverted and demodulated. Such a radio could be programmed to handle a wide variety of analog and digital signals using the same hardware.

Multimode Digital Radio

- Universal cellular radio operating on multiple bands with programmable modulation and coding
  - DARPA Speakeasy program
  - "Software" radio - BellSouth RFI
- Ultra high speed analog to digital converters enable simple implimentations
  - DARPA A/D Converter Program heterojunction bipolar technology (HBT)
  - Rockwell 8 bit 3Gs/s ADC, 12 bit 1GHz DAC
  - TRW 4 bit 3Gs/s ADC



Improved Power Supplies

Because the batteries required to operate portable electronics during a field mission are heavy and expensive, weight reduction via improvements in specific energy (energy/mass) and power efficiency are critical issues for the Army.

Because transmit power is proportional to the signal bandwidth, the use of high bandwidth communications for video and network links should be examined carefully. The received energy required per bit of information is fixed at a multiple of the temperature (ideally for signal-to-noise ratio SNR = 1 the energy per bit is ~ kT with k Boltzmann's constant and T the temperature). As shown, the estimated transmitted power required to achieve a signal-to-noise ratio SNR = 100 at 10 km distance for S band transmission increases from 200 mW for voice transmission at 10 kbit/sec to 20 W for low resolution video at 1 Mbit/sec. These differences have a real influence on power consumption and the resulting logistics.

Significant improvements in specific energy $e = E/m$ (energy/mass) are achievable using fuel cells, because the cell can be refueled. The mass of the empty fuel cell need not be repeated for each load of fuel, unlike batteries. As a result, the fuel cell mass becomes unimportant compared with the mass of the fuel over many refuelings, as shown in the formulae, and the limiting specific energy approaches that of the fuel alone $e_{fuel} = E_{fuel}/m_{fuel}$.

Improved Power Supplies

- Portable battery packs heavy and expensive.
- High-bandwidth radio increases power demands.

Estimated Power (S-band transmission, SNR=100)

Bandwidth	R= 100 m	R = 1 km	R = 10 km
10^6 bits/s	2 mW	200 mW	20 W
10^4 bits/s	.02 mW	2 mW	200 mW

- Significant improvements in overall specific energy e = *E/m* are achievable with fuel cells:

Battery : $e = \frac{E_{\mathbf{fuel}}\varepsilon}{(m_{\mathbf{fuel}} + m_{\mathbf{cell}})}$ **Fuel Cell :** $e = \frac{NE_{\mathbf{fuel}}\varepsilon}{(Nm_{\mathbf{fuel}} + m_{\mathbf{cell}})}$

where ε = efficiency , N = no. refuelings

Improved Power Supplied
(concluded)

Hydrogen fuel cells have high specific energy e_{fuel} @ 60 kW-hr/kg, compared with the specific energy of Lithium/SO2 batteries e @ 300 W-hr/kg, but hydrogen requires a heavy storage container. Methanol fuel cells appear more practical, and give sizable improvements in specific energy e_{fuel} @ 5.8 kW-hr/kg. Research in direct methanol oxidation and in methanol-to-hydrogen conversion cells has achieved efficiencies e ~ 30%.

DARPA's Advanced Fuel Cell Technology program anticipates procurement of prototype direct methanol conversion cells in the near future with specific energy emethanol @ 5eLi. Large fuel cells to replace mobile electric power generators are also under development.

Improved Power Supplies

(concluded)

- Lithium/SO_2 batteries have $e \approx 300$ W-hr/kg
- Hydrogen fuel cells have $E_{fuel}/m_{fuel} \approx 60{,}000$ W-hr/kg, but hydrogen container is heavy.
- Methanol fuel cells have $E_{fuel}/m_{fuel} \approx 5800$ W-hr/kg.
- Research in direct methanol oxidation, and in methanol-to-hydrogen conversion cells has achieved efficiencies $\varepsilon \sim 30\%$.
- DARPA's Advanced Fuel Cell Technology program anticipates procurement of prototype direct-methanol conversion cells in 6 to 12 months with specific energy $e_{\text{methonal}} \approx 5\ e_{\text{Li}}$
- Large fuel cells suitable to replace mobile electric power generators are also in development under DARPA program.

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Summary

Advantages of COTS for the Army

The use of universal data transfer standards will greatly simplify the networking of Army communications systems. As amply demonstrated by the success of the Internet, the use of standard protocols can make radical improvements in the ease of data transfer across widely differing platforms. The use of TCP/IP protocols has been mandated in the Army, including adaptation of legacy systems. We fully agree with this step. The ATM standard should also be adopted by the Army for high capacity links, and the interface between ATM and TCP/IP examined.

The market for sophisticated electronics systems has now largely shifted from the military to the commercial sector. Economies of scale permits COTS technology to offers high performance electronics with wide availability at low cost.

Cellular telephone communications systems are designed from the outset as a mobile system. Cellular phones are light weight and low cost, and many necessary features of the system have been worked out, such as hand-off between neighboring cells.

Satellites used as part of a cellular telephone network can provide nearly universal access to remote areas throughout the world.

Digitized voice signals can be easily adapted for data transmission, error correction, and encryption.

CDMA coding provides a form of spread spectrum communication that can be adapted for anti-jam capability and low probability of interception.

Multilevel security systems have been worked out and can be added to a cellular network.

Advantages of COTS for the Army

- Universal data transfer standards.
  - TCP/IP mandated, adapt legacy systems
  - Adopt ATM for high capacity links
- Low cost, wide availability.
- Cellular radio designed as mobile system.
- Satellites provide universal access to remote areas.
- Digital voice easily adapted for error correction, encryption, data transmission.
- CDMA coding can be adapted for anti-jam, low probability of interception.
- Multilevel security can be added.

Shortcomings of COTS for Military Use

Commercial cellular telephone and PCS networks use line-of-sight frequencies, ~800 MHz and ~1.8 GHz respectively. Radio signals at these frequencies are strongly absorbed by vegetation and easily blocked by obstructions. Commercial cellular systems use a large network of base stations to mitigate these difficulties, but the need to create a base station network poses problems for military use, as discussed below.

Commercial cellular systems use a fixed network of base stations connected by high capacity, low error rate links. High power and high bandwidth tasks are off-loaded to the base station network to permit the use of light weight handsets. A military system cannot assume the pre-existence of a functional network of base stations in the theater of operations. The base station network must be created using a mix of mobile ground stations, unmanned aeronautical vehicles (UAVs), and satellites. Unlike commercial units, military base stations must be able to maintain high bandwidth connections in a dynamically changing network to accommodate for motion of the mobile basestation units, losses, and poor signal-to-noise ratio (SNR). These requirements are more severe than for commercial systems and will require different approaches to system control and different hardware.

The data transmission bandwidth is generally limited in COTS cellular to values appropriate for voice transmission. The transmission of digital imagery and video will require modifications in coding as well as higher transmit power. The limited bandwidth of commercial cell phones also permits low power jamming of base stations, UAVs, and satellites, even for "spread spectrum" CDMA systems. For example, a stolen CDMA handset could be connected to an rf amplifier of moderate power to saturate all of the channels available in the base station. Current satellites for cellular telephone systems have limited capacity ~1000 channels for large military operations. UAVs and mobile ground basestations will be needed to carry the bulk of the traffic.

Shortcomings of COTS for Military Use

- Line of sight frequencies (~800 MHz, ~1.8 GHz).
- Assumes fixed network of base stations connected by high capacity, low error rate links.
  - Need mobile ground base stations, UAVs, or satellites
  - Dynamically changing network - motion, losses, poor SNR
- Data bandwidth limited in COTS cellular.
  - Transmission of imagery, video not standard
  - Low power jamming of base stations,UAVs and satellites
  - Many base stations required for large operations (UAVs?)
  - Satellites have ~1000 channel capacity only

R&D to Adapt COTS to Army Needs

These concluding slides summarize a number of areas where research and development efforts are needed to adapt commercial off the shelf communications systems to Army needs.

In recent years it has become clear that the use of commercial off the shelf technology can improve performance and reduce costs for military equipment. Sometimes the extreme point of view has been put forward that the Army need only buy communications equipment built to civilian specifications from commercial suppliers. As described above, military operations place demands on communications systems quite unlike those encountered in the civilian world, and unmodified commercial systems can be used only in limited number of circumstances. A sensible course of action might be to use standards and components from COTS systems where possible, and to conduct research and development efforts to adapt these components to Army needs.

A major area where work is needed is the development of mobile and flexible network of base stations for cellular communications connected by high speed lines. For the amount of traffic needed in large operations, a large number of mobile ground stations and/or UAV base stations will be needed. These base stations can use COTS communications standards with certain changes and additions:

• Adaptive network control will be needed to correct for changing communications links and network topology as a result of motion and losses.

• Priority and timeliness protocols will need to be developed to implement the chain of command in an efficient manner. For example the all to all access in current systems is not well suited to the military, and certain messages - incoming fire - should be handled by the system as rapidly as possible.

R&D to Adapt COTS to Army Needs
(continued)

- The transmission of pictures and digital data is not yet standard in commercial cellular equipment, and special capabilities will need to be developed for these purposes. A particular concern is the wide bandwidth required by visual images and the associated increases in power consumption.

High bandwidth links will be needed to interconnect mobile ground stations. These must be suitable for deployment on a truck or UAV, limiting the antenna configurations possible, and placing special emphasis on low weight and low power consumption. For UAVs these restrictions will be especially severe. Communications links could include high capacity trunk radio, and for ground operations fiber optics links.

Military communications will benefit from the development of high speed data conversion electronics and from advanced power sources.

- Recent progress in microwave digital to analog and analog to digital converters at Rockwell and TRW, sponsored in part by DARPA, point the way to the development of a universal digital radio whose frequency and coding can be programmed by software commands. The commercial world is also very interested in such units, and the price of these new DACs and ADCs could become very reasonable if produced in quantity.

- Improvements in efficiency, and the development of high specific energy fuel cells and other types of advanced power sources are of critical importance to the Army.

R&D to Adapt COTS to Army Needs
(continued)

The use of commercial satellite systems for military communications should be investigated. A number of new satellite constellations (Globalstar, Iridium, COMSAT, etc.) are in advanced stages of development or early deployment. These are aimed at somewhat different markets and have differing characteristics. For example, the Globalstar system will function as "bent pipe" relays to expand the coverage around fixed ground stations, whereas the Iridium satellites form their own network. Satellites appear well suited to intelligence gathering and special operations, as well as to supplement a ground and UAV based network for improved coverage and reliability. However, the total capacity of planned satellite systems is not sufficient to carry more than a small fraction of the traffic in a major military operation. Global satellite systems with international business agreements may be sensitive to involvement with the U.S. military.

Summary

R&D to Adapt COTS to Army Needs

- Mobile ground base stations and UAVs
  - Develop adaptive network control for changing nets, links.
  - Priority, timeliness protocols.
  - Develop multimedia, multicast capabilities.
- High capacity links for theatre
  - High capacity trunk radio
  - Fiber optic links
- Develop electronics for digital radio
  - High speed ADCs and DACs
  - Fuel cells and advanced power sources
- Investigate use of commercial satellite systems

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R&D to Adapt COTS to Army

The data bandwidth of COTS cellular radio systems needs to be increased for certain military uses. Cellular telephone systems are typically designed for voice with bandwidths ~10kHz per channel. This bandwidth is insufficient for imagery or serious anti-jam and low-probability of intercept (AJ/LPI) applications. Commercial systems and standards could be modified to increase their bandwidth in a number of ways:

- Combine the 13 channels of current CDMA systems to provide one channel with increased bandwidth (16.5 MHz).

- Investigate optimal coding schemes built on top of the channel architecture of cellular radio systems by switching and combining channels.

- Research AJ/LPI approaches designed on top of commercial coding schemes using wider bandwidth and frequency hopping.

- Adapt COTS cellular for the transmission of imagery and video. The transmission of imagery in real time will require careful consideration of power and bandwidth constraints, and may lead to protocols as to when such transmissions are made.

Computer software will be needed for military applications. The Battlefield Data Interface and Appliqué are two examples of programs which have been developed to suit military needs.

R&D to Adapt COTS to Army Needs
(concluded)

In using COTS systems, the military should not lose sight of the fact that COTS is not a standard, that COTS systems evolve with the marketplace, and that COTS systems become obsolete. The time scale for changes may often be too rapid for military use, and backward compatibility is no guaranteed. The military will need to analyze its use of COTS systems over the long term and add military standards where needed.

Summary

R&D to Adapt COTS to Army Needs

(concluded)

- Increase data bandwidth of COTS systems
  - Modify CDMA to combine all 13 channels (16.5 MHz)
  - Investigate optimal coding schemes
  - Research anti-jam, low probability of intercept approaches using wider bandwidth, frequency hopping
  - Adapt COTS cellular for imagery, video
- Develop software for military
  - Battlefield Data Interface, Applique
- Changing commercial standards will require continuous adaptation by the military
  - COTS is not a standard
  - Hardware and (especially) software will change.

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